

APPLICATION FOR
UNITED STATES LETTERS PATENT
SPECIFICATION

Inventor(s): Masaki UKAI

Title of the Invention: DEVICE AND METHOD FOR
CONTROLLING WRITING OF BRANCH
HISTORY INFORMATION

09532275, 032100

**DEVICE AND METHOD FOR CONTROLLING WRITING OF BRANCH
HISTORY INFORMATION**

Background of the Invention

5

Field of the Invention

The present invention relates to a device for
controlling the writing of branch history information
in an information processing apparatus provided with
a branch estimation unit.

10

Description of the Related Art

In an instruction execution processing apparatus,
performance is improved by using technologies
including a pipeline process and sequentially starting
the execution of subsequent instructions without
waiting for the completion of a specific instruction.
In this case, if a previous instruction is an
instruction to change the execution sequence of a
subsequent execution, such as a branch instruction,
etc., and a branch is established, the execution
pipeline is impeded, and in the worst case, the
performance is degraded if an instruction on the
branch destination is not inputted to the execution
pipeline. Under these circumstances, a branch

15

20

25

09532275.032100

prediction unit represented by a branch history is provided and the establishment of a branch is predicted. If a branch establishment is predicted, the performance could be improved by inputting an instruction on the branch destination following a branch instruction to an execution control unit or instruction process unit.

However, in a conventional branch prediction unit, the branch history information of a branch instruction of which the execution is completed in a branch control unit was registered in a branch history by temporarily stopping the instruction fetch.

According to this system, in particular, if a branch prediction fails and a correct subsequent instruction is re-executed, and specifically, if a re-instruction fetch occurs, an instruction fetch pipeline is temporarily stopped by the branch history information writing the completed branch instruction into the branch history although the frequency of a fetch request is high since a temporary instruction buffer is empty. Accordingly, the performance was not improved.

Specifically, although, as in the execution of a branch instruction BC shown in Fig. 1, in the cycle W of the execution cycle of a branch instruction, the

09532275-032100

5

10

15

25

Summary of the Invention

An objective of the present invention is to provide an instruction execution control device for suppressing a process delay in an information processing apparatus provided with a branch prediction unit, and a method thereof.

A device in the first aspect of the present invention comprises a control unit controlling in such a way that the writing of branch history information into a branch prediction unit and the control over the memory unit may not occur simultaneously in a branch history information write control device in an instruction execution processing apparatus provided with a memory unit storing an instruction string, etc., and a branch prediction unit performing the branch prediction of a branch instruction.

In a branch history information write control device of an instruction execution processing apparatus provided with a branch prediction unit performing the branch prediction of a branch instruction, a device in the second aspect of the present invention comprises a return address stack unit and a control unit controlling in such a way that if the branch instruction is not executed although the branch instruction is an instruction corresponding to

09532275-032100

09532275-032100

a sub-routine call or return, and the write request of the branch history information of the branch instruction is issued to the branch prediction unit, the branch history information is written in the branch prediction unit, but the return address stack unit may not be operated.

A method in the first aspect of the present invention is an instruction control method in an apparatus provided with a memory storing an instruction string, etc., and a branch prediction unit performing the branch prediction of a branch instruction, and comprises the step of controlling in such a way that the writing of branch history information in the branch prediction unit and the control over the memory may not occur simultaneously.

A method in the second aspect of the present invention is an instruction control method in an apparatus provided with a branch prediction unit performing the branch prediction of a branch instruction and a return address stack, and comprises the step of controlling in such a way that if the branch instruction is not executed although an instruction corresponding to the sub-routine call or return obtained as an execution result of the branch instruction issues the write request on the branch

history information to the branch prediction unit, the branch history information is written in the branch prediction unit, but the return address stack is not operated.

5 Although conventionally an instruction fetch is held and branch history information is written in the branch prediction unit (branch history), according to the present invention, an instruction fetch is not held and the branch history is written in a branch
10 history in a timing such that the writing of the branch history information in the branch history and the control of the instruction fetch, etc., over a memory may not occur simultaneously. Accordingly, no instruction fetch is held and thereby the execution
15 process speed can be improved.

Brief Descriptions of the Drawings

Fig. 1 shows conventional problems occurring at the time of execution of a branch instruction.

20 Figs. 2A and 2B show conventional problems occurring when a short loop is formed between branch instructions.

Fig. 3 shows effects obtained when a branch instruction is executed according to the present
25 invention.

0953275.032100

Figs. 4A and 4B show effects obtained when a short loop is formed between branch instructions according to the present invention.

Fig. 5 shows the basic configuration of the preferred embodiments of the present invention.

Fig. 6 shows an example configuration of a branch history.

Fig. 7 shows an example basic configuration for delaying the writing of the branch history information of a branch instruction re-instruction-fetched.

Fig. 8 shows an example detailed configuration of a block 31 shown in Fig. 7.

Fig. 9 shows an example detailed configuration of a block 32 shown in Fig. 7.

Fig. 10 shows an example of a circuit corresponding to a block 30 shown in Fig. 7.

Fig. 11 is a timing diagram of a preferred embodiment using a counter.

Fig. 12 shows another preferred embodiment of a circuit corresponding to a box 30 shown in Fig. 7.

Fig. 13 shows an example circuit configuration for operating the device even if a temporary instruction buffer is empty.

Fig. 14 shows another preferred embodiment of a circuit of a box 30 shown in Fig. 7 (No. 1).

0953275-032100

a write reservation station.

Fig. 25 shows an example configuration of a reservation station in the case where writing in a reservation station is available after the completion of an instruction execution under IID (Instruction ID) control.

Fig. 26 shows an example configuration of the CSE valid circuit of a write reservation station.

Fig. 27 shows the data storage configuration of a write reservation station.

Fig. 28 shows an example configuration of a CSE valid circuit in the case where a branch prediction unit is provided with a return address stack.

Fig. 29 shows an example circuit for nullifying the entry of a reservation station if an instruction execution is temporarily stopped due to an interruption, etc.

Fig. 30 shows one preferred embodiment of a bypass hit circuit.

Description of the Preferred Embodiments

In the preferred embodiment of the present invention, the writing of branch history information is held while a branch history is being looked up, and the branch history information is written in a cycle

information. If instruction fetch requests continue, and, even if an instruction pipeline process is very smoothly executed, the impediment of an instruction fetch request can be eliminated by providing a reservation station as a holding device for realizing such a buffer function. Accordingly, the performance degradation can be prevented.

If there is a new write request while branch history information is being held by the holding device, a control method for preventing a reservation station which becomes a temporary buffer, from overflowing is provided. According to such a preferred embodiment, all branch history information can be registered/updated in a branch history without failure.

Depending on the configuration of a branch history, a plurality of branch histories can be simultaneously written in the same cycle. In a branch history comprised of a plurality of RAMs (random access memory) which can store another entry, a maximum of the same number of different entries as RAMs composing the branch history can be written. It is clear that by doing so, a lot of history information of branch instructions can be written in a branch history while the impediment of writing for

09532275-032100

The registration/update of the branch history information is held until an instruction execution is completed. In this case, the branch history information can be written simultaneously with the execution completion or the writing can be held until there is a favorable timing. In this case, alternatively, a method for identifying an instruction with an ID number assigned for each instruction can be used to judge whether the execution of the branch instruction is completed. If the execution of the branch instruction is cancelled although the branch history information is transmitted, the relevant entry corresponding to the write reservation station can also be nullified. In this case, since the history information of a branch that has been executed with certainty is to be used if the writing is held until the execution is completed, no incorrect branch history information is registered and thereby the accuracy of a branch prediction is improved.

If a branch prediction is performed by a branch prediction unit, branch history information, writing of which is held, etc., can also be used by bypassing

the writing. In this case, since bypassing was performed, the latest branch history information can be used, and an enhanced effect can be obtained, in particular in a local loop. Specifically, the process
5 delay of a pipeline can be improved by approximately several clock cycles for each short loop.

For example, if, as shown in Figs. 4A and 4B, short loops shown in Figs. 2A and 2B are executed, conventionally, as shown in Figs. 2A and 2B, the
10 instruction fetch of the instruction L(3) of the third loop is started in a cycle B of the execution cycle of the instruction L(2) of the second loop. However, in Figs. 4A and 4B, the instruction fetch of the instruction L(3) is started in the timing of the cycle
15 IB of the instruction L(2) by bypassing the writing and using the branch history information. In this way, according to this preferred embodiment, performance can be improved by six clock cycles compared with the conventional method shown in Figs. 2A and 2B.

20 As the RAMs of a branch history, dual port RAMs which can perform writing and reading independently in the same cycle, are used. If there is room in circuit mounting, the performance degradation can be prevented most easily using this method.

25 Fig. 5 shows the basic configuration of the

09532275-032100

preferred embodiments of the present invention.

The instruction execution control device of the present invention adopts an out-of-order system. Therefore, in Fig. 5, which concerns an execution control unit, only approximate time dependency is shown.

In this preferred embodiment, it is assumed that an instruction fetch can secure an instruction string of 16 bytes which is 8-byte-aligned, at one request.

10 First, the address of an instruction to be fetched next is inputted to a selector 11. The addresses to be inputted to the selector 11 are the sequential instruction address which is inputted from an adder 10, the start address for an interruption process, the prediction branch destination instruction address which is the branch prediction result inputted from a branch history, and the branch destination instruction address which is confirmed by a branch instruction process unit 17 executing a branch instruction. The selector 11 is controlled by an instruction execution flow control device (not shown in Fig. 5) which is controlled by an instruction completion process unit 19 for guaranteeing the order of instructions in an out-of-order type information processing apparatus, and is configured to select an

15
20
25

001220" 5 222550

branch instruction process unit 17 and execution instruction process unit 18 are processed by an instruction completion process unit 19, and are used to guarantee an instruction execution order and to control an out-of-order type instruction execution order. The address of a branch destination instruction which is determined as an execution result of the branch instruction is inputted to the selector 11 from the branch instruction process unit 17.

Fig. 6 shows an example configuration of a branch history.

The branch history 20 is comprised of two RAMs 20-1 and 20-2, and these two RAMs 20-1 and 20-2 are configured to search for branch history information in the ranges of high-order 8 bytes and low-order 8 bytes, respectively, using an 8-byte-aligned instruction fetch address. According to this preferred embodiment, the branch history 20 is provided with a return address stack to predict the return destination of a sub-routine return instruction, which is not shown in Fig. 6.

According to this preferred embodiment, the branch instruction process unit 17 in the execution process unit can handle a maximum of four branch instructions, a maximum of one out of four branch

process unit 17 issues a correct branch destination address (or subsequent instruction address) and makes a request for a re-instruction fetch.

At this time, if an instruction cache 13 cannot
5 accept the request for some reason, the re-instruction
fetch request is held until the request can be
accepted. While the re-instruction fetch request is
being held, +REIFCH_REQUEST remains ON. In this case,
usually this signal is directly inputted to the block
10 30. However, a circuit shown in Fig. 13, which is
described later, is provided and a signal outputted
from this circuit can also be inputted to the block
30 instead.

In this case, there is a possibility that the
15 timing of issuing the request and the timing of
writing into the branch history may match. In that
case, according to the prior art, priority is given
to writing into the branch history 20, and the re-
instruction fetch request is further delayed by one
20 or more clock cycles. According to this preferred
embodiment, since priority is, without fail, given to
the re-instruction fetch request, conventional
performance degradation does not occur.

If the re-instruction fetch request
25 (+REIFCH_REQUEST of "H") is inputted to the block 30,

both a signal obtained by logically inverting a signal for holding the writing of branch history information in the branch history 20 (-WAIT_BR_COMP_WRITE) and a signal for holding the re-instruction fetch signal of a re-instruction fetch (+BR_COMP_REIFCH_HOLD) are outputted. +BR_COMP_REIFCH_HOLD is inputted to the block 31. -WAIT_BR_COMP_WRITE is inputted to the block 32. The block 31 receives branch information, such as +BR_COMP_AS_TAKEN, etc., and further, a branch instruction address (+BR_COMP_IAR) and a branch destination instruction address (+BR_COMP_TIAR) are inputted to the block 31. Then, a signal for controlling an instruction to write in the branch history (+CREATE_NEW_ENTRY, +UPDATE_OLD_ENTRY, +ERASE_ENTRY), branch history information, a signal obtained by latching a branch destination instruction address (+BR_COMP_IAR_LCH), and a signal obtained by latching a branch destination instruction address (+BR_COMP_TIAR_LCH) are outputted from the block 31. The branch history information and branch destination instruction address are inputted to the port for writing data of the branch history 20. The branch instruction address is inputted to the selector 34 together with an instruction fetch address (+IF_EAG). A signal for instructing to write in the branch

00532275.032100
007220" 5222560

history 20 is outputted from the block 32. By this
 signal, an appropriate address is outputted from the
 selector 34. Simultaneously, the branch history 20 is
 made to enter a writable state, and the branch history
 5 information, etc., can be written.

Fig. 8 shows an example circuit detail of the
 block 31 shown in Fig. 7, which stores data while
 writing is being held up.

A signal obtained by logically inverting a signal
 10 indicating whether the update of the entry of the
 branch history 20 is valid (-BRHIS_UPDATE_VALID) and
 +BR_COMP_REIFCH_HOLD are inputted to an AND circuit
 41. Therefore, if the update of the entry of a branch
 history is invalid and a re-instruction fetch is
 15 requested, branch history information, a branch
 instruction address and a branch destination
 instruction address are stored in a latch circuit 42.
 The branch history information, branch instruction
 address and branch destination instruction address are
 20 outputted from the latch circuit 42. As described with
 reference to Fig. 7, simultaneously,
 +CREATE_NEW_ENTRY, +UPDATE_OLD_ENTRY, +ERACE_ENTRY,
 which are signals for instructing to write in the
 branch history 20, are extracted from the branch
 25 history information and are outputted from the latch

(see Fig. 11(d)), writes branch history information in a branch history (see Fig. 11(e)) and returns to an execution waiting (re-instruction fetch request waiting) state. Since by using this method, priority
 5 is given to these three instruction fetch requests over a normal re-instruction fetch, this method is applicable to a case where the temporary instruction buffer 14 is empty as well as to a temporary instruction fetch request. In this case, an output
 10 shown in Fig. 13 can be inputted instead of a signal +REIFCH_REQUEST, which is one of the input signals shown in Figs. 7 and 10.

Specifically, the counter shown in Fig. 10 is comprised of two bits, and if +REIFCH_REQUEST is
 15 inputted, a signal of positive logic and a signal of inverted logic are inputted to one terminal of an AND circuit 61 and one terminal of an OR circuit 62, respectively, via a latch circuit 60. In Fig. 10, <0> is a high-order bit and <1> is a low bit. If a re-
 20 instruction fetch signal is "H", the value stored in a latch circuit 63 becomes "01", and is maintained. If the re-instruction fetch signal becomes "0", "0" and "H" are outputted from the terminal Q of the latch circuit 60 and the inverted terminal of Q,
 25 respectively. Therefore, if a counter value "01" is

outputted via an EXOR circuit 64, an inverter 65, an OR circuit 66 and AND circuits 67 and 68, both of the counter values outputted from the AND circuit 61 and OR circuit 62 become "10". Since "10" is stored in the latch circuit 63, the output of the EXOR circuit becomes "1", and the outputs of the inverter 65 and OR circuit 66 also become "1". Therefore, both of the outputs of the AND circuits become "1". Then, the re-instruction fetch signal becomes "0". Therefore, "11" and "10" are inputted to the AND circuit 61 and OR circuit 62, respectively, and the value of the counter of two bits becomes "11". If in this way, the re-instruction fetch signal becomes "0", the counter starts counting up to "11". When the count value reaches "11", the count value returns to "00". In response to this count value, the EXOR circuit 69 outputs a re-instruction fetch hold signal +BR_COMP_REIFCH_HOLD when the count value is "01" or "10" (see Fig. 11D). When the count value is "00" or "11", a signal for permitting to write in the branch history 20 -WAIT_BR_COMP_WRITE is outputted.

As described above, if a re-instruction fetch signal of "H" is inputted, the count value changes from "0" to "1", and if the re-instruction fetch signal drops to "L", the count value is counted up.

5

10

15

25

A circuit shown in Fig. 13 provides a signal which replaces +REIFCH_REQUEST, as the input of the box 30 shown in Fig. 7. Specifically, (1) if an instruction buffer 14 is empty (+I_BUFF_EMPTY is "H"),
 5 (2) if in a cycle IT, an instruction fetch request is invalid (-IT_IF_REQ_VALID is "H") and (3) if in a cycle IB, the instruction fetch request is invalid (-IB_IF_REQ_VALID is "H"), the output of an AND circuit 91 becomes "H". Therefore, if the three conditions,
 10 (1) to (3), above are met or if there is a re-instruction fetch request (+REFECH_REQUEST is "H"), a signal +REIFCH_REQ_OR_IF_EMPTY becomes ON. Then, this signal is inputted to the box 30 shown in Fig. 7 instead of a re-instruction fetch signal.

15 Figs. 14 and 15 show another preferred embodiment of the box 30 shown in Fig. 7.

Fig. 14 shows an example configuration of the box 30 in the case where if there is a re-instruction fetch, branch history information is not written in the branch history 20, but if the instruction cache
 20 13 cannot accept an instruction fetch, the branch history information is written in the branch history 20. In this case, not an instruction fetch request, but a signal +SU_BUSY, which is transmitted from the
 25 instruction cache 13, is inputted as input. The fact

00532275.032100
 007220"5222560

that this signal is "H" means that since the instruction cache 13 is full, and an instruction fetch cannot be accepted. In this case, if a signal +SU_BUSY of "H" is inputted, a write permit signal of "H" (+BR_COMP_WRITE) is outputted from a buffer 101 to the branch history 20. If a signal +SU_BUSY of "H" is not inputted, a signal for instructing to temporarily hold a re-instruction fetch of "L" (+BR_COMP_REIFCH_HOLD) is outputted from an inverter 102.

Fig. 15 shows an example circuit configuration of the box 30 shown in Fig. 7 in the case where if there is a request on a real instruction fetch, such as the pre-fetch of an instruction, branch history information is written in the branch history 20. In this case, if a signal, such as an instruction pre-fetch request, etc., is inputted as input, and this signal is "H", a signal for permitting to write in a branch history of "H" (+BR_COMP_WRITE) is outputted from a buffer 111. If the signal is "L", a signal for instructing to temporarily hold a re-instruction fetch of "H" (+BR_COMP_REIFCH_HOLD) is outputted.

Fig. 16 shows an example configuration of a branch history write reservation station.

When an entry is registered in a reservation station, a valid flag (Valid) is set, and by using the

signal as a hold signal, branch prediction data (branch history information) is held.

If a reservation station 120 (120-1) shown in Fig. 16 is used, writing in the branch history 20 can also be controlled by using one of the preferred embodiments described above.

The reservation station 120 is comprised of four entries (RSW0-RSW3). In each entry RSWx (x=0-3), a valid flag (Valid) and an instruction address (IAR) are registered, and further branch history information 121 corresponding to the registered instruction is stored.

Fig. 17 shows the overall circuit configuration of a preferred embodiment which controls writing in the branch history 20 in the case where the reservation station 120 shown in Fig. 16 is used.

First, branch history information (+BR_COMP_AS_TAKEN, etc.) is inputted to the reservation station 120 by the branch instruction execution unit, and simultaneously both a branch instruction address (+BR_COMP_IAR) and a branch destination instruction address (+BR_COMP_TIAR) are also inputted. The reservation station 120 is configured as shown in Figs. 16 and 22-25. From the reservation station 120, data to be written in a

09532275 032100

branch history for odd addresses 20-1 and a branch history for even addresses 20-2 are outputted via a selector 130 shown in Fig. 21 (+BRW_ODD/EVEN_DATA). Signals outputted from the reservation station 120 are

5 processed in a block 140 to generate an odd address branch history write permit signal (+RSW_ODD_WRITE_VAL) and an even address branch history write permit signal (+RSW_ODD_WRITE_VAL), respectively, which become signals for permitting to

10 write in the branch histories 20-1 and 20-2, respectively. In a selector 150, either an address IAR transmitted from the reservation station 120 or an address for retrieving from the branch history 20 (+IF_EAG) is selected. In particular, if a write

15 permit signal is received from the block 140, the selector 150 selects the IAR and makes a certain circuit write in the branch history 20. For example, the writing in the branch history 20 is performed by a circuit shown in Fig. 22.

20 In this preferred embodiment, plurally and simultaneous writing is also performed.

Figs. 16-20 show control circuits for plurally and simultaneously writing in the branch history 20.

In this preferred embodiment, the branch history

25 is comprised of two RAMs. Therefore, if there are two

09532275-032100

pieces of branch history information which can be written in the entries of different RAMs, the two different pieces of branch history information can be written in the same cycle.

5 Fig. 18 shows a selection circuit for plurally and simultaneously writing in a branch history (No. 1).

10 In the circuit shown in Fig. 18, when simultaneous writing in the two branch histories 20-1 and 20-2 is available, a signal +WRITE_DOUBLE is ON.

15 In Fig. 18, two valid flags of the entry of the reservation station 120 (+RSWx_VALID) are inputted to each of six AND circuits 141-1 - 141-6. A circuit 140A located in the upper section of Fig. 18 is a write signal selection circuit used when one entry of the reservation station 120 is written into the branch histories 20-1 and 20-2. If the two valid flags are added up and both of them are valid, a signal of "H" is inputted to one of the AND circuits 142-1 - 142-6.

20 If the fourth bits from the right ends of the addresses of the entries of two reservation stations RSWx are compared and the bits are different, "H" is inputted to the input terminal of another of the AND circuits 124-1 - 142-6. This is because in the branch

25 history 20, an instruction is stored in units of 16

bytes and if there are 16 or more different write addresses, the addresses are written in the low-order 8 bytes and the high-order 8 bytes of the branch histories 20-1 and 20-2, respectively. Then, the device is controlled in such a way that the combinations of two addresses with priority are written in the branch history 20 with priority in a priority determination circuit 143. If the signal of one of the AND circuits 142-1 - 142-6 is ON, a plurally writable signal (+WRITE_DOUBLE) is outputted.

A circuit 140B located in the lower section of Fig. 18 is a write signal selection circuit used when one entry of the reservation station 120 is written into the branch history 20. If either of the valid signals of the entry of each reservation station RSWx is ON, a signal indicating that data to be written is available (+WR_DATA_AVAILABLE) is outputted. Priority is set to the writing of each entry of the reservation station 120 by a circuit 146. If a plurally writable signal is OFF and +WR_DATA_AVAILABLE is "H", a single write signal (+WRITE_SINGLE) is outputted and simultaneously a signal indicating which entry of the reservation station 120 should be written (+WRITE_RSWx) is outputted.

In Fig. 18, the output of this AND circuit can

Fig. 19 shows a selection circuit for plurally and simultaneously writing in a branch history (No. 2).

In Fig. 19, the output from the single write selection circuit 140B shown in Fig. 18 and the 28th bit of an instruction address (IAR) outputted from the reservation station 120 are inputted to AND circuits 151 (151-1 - 151-4). By checking whether a write signal inputted from the single write selection circuit and the 28th bit of an instruction address are ON or OFF, a write permit signal used when the instruction address is odd, is outputted. Then, if one of the AND circuits 151-1 - 151-4 is ON, the writing of an odd address is permitted. Therefore, if this signal is outputted, a signal for permitting to write

in the odd branch history 20-1 (+RSW_ODD_WRITE_VALID) is outputted. If the double write signal (+WRITE_DOUBLE) is ON, writing in the odd branch history 20-1 and even branch history 20-2 are permitted. Specifically, +RSW_ODD_WRITE_VALID and +RSW_EVEN_WRITE_VALID are turned ON. If the writing in the odd branch history 20-1 is OFF, a signal to be inputted to an AND circuit 66 becomes ON. Furthermore, if the single write signal (+WRITE_SINGLE) is ON, a signal for permitting to write in the even branch history 20-2 (+RSW_EVEN_WRITE_VALID) becomes ON. If either a signal indicating that writing in the branch history 20 is not held (-WAIT_BR_COMP_WRITE) or a signal for compulsorily writing in the branch history 20 (+FORCE_WRITE_BRHIS) is ON, this signal for permitting to write in the odd or even branch history is outputted. +FORCE_WRITE_BRHIS is described later.

Figs. 20 and 21 show selection circuits for plurally and simultaneously writing in branch histories (No. 3) (No. 4).

A circuit shown in Fig. 20 generates select signals for writing in the entries RSW0-RSW3 of the No. 1 through No. 3 branch histories of the reservation station 120 (+SEL_RSWx_WRITE) using the output shown in Fig. 18 as input, and inputs the

signals to a circuit shown in Fig. 21.

The circuit shown in Fig. 21 selects data transmitted from the reservation station 120 (RSW_x_DATA). In Fig. 21, a selection circuit for an odd branch history 20-1 and a selection circuit for an even branch history 20-2 are separately configured. Data from the reservation station 120 are inputted to multiplexers 181 and 182, and one of the pieces of data is transmitted as RSW_OLD_DATA or RSW_EVEN_DATA.

The multiplexer 181 adds a select signal (+SEL_RSW_x_WRITE), which is the output of the circuit shown in Fig. 20, to the 28th bit of an instruction address (IAR) inputted from the RSW0 to RSW3 of the reservation station 120, and switches the operation based on the result. In this way, if the select signal is ON and the instruction address is odd, a select signal is transmitted and corresponding data are transmitted.

In the same way, the multiplexer 182 adds a select signal, which is the output of the circuit shown in Fig. 20, to a signal obtained by logically inverting the 28th bit of an instruction address inputted from the RSW0 to RSW3 of the reservation station 120, and switches the operation based on the result. In this way, if the select signal is ON and

09532275-032100

the instruction address is even, corresponding data are transmitted.

Fig. 22 shows a circuit for plurally and simultaneously writing in a branch history.

5 An address for writing an instruction in the odd branch history 20-1 (RSW_ODD_IAR) and an address for reading from the branch history (IF_EAG) are inputted to a selector 191. In the same way, an address for writing an instruction in the even branch history 20-2
10 (RSW_EVEN_IAR) and an address for reading from the branch history 20 (IF_EAG) are inputted to a selector 192. +RSW_ODD_WRITE_VALID, which is the output of the circuit shown in Fig. 19, is also inputted to the selector 191. The device is configured in such a way
15 that if writing in the odd branch history 20-1 is permitted, the selector 191 selects RSW_ODD_IAR. Similarly, the device is configured in such a way that if +RSW_EVEN_WRITE_VALID, which is the output of the circuit shown in Fig. 19, is inputted and writing in
20 the even branch history is permitted, the selector 192 selects the RSW_EVEN_IAR. Write-enable is set in the odd branch history 20-1 and even branch history 20-2 by +RSW_ODD_WRITE_VALID and +RSW_EVEN_WRITE_VALID, respectively, and RSW_ODD_DATA and RSW_EVEN_DATA,
25 respectively, are written.

00532275-032100

Furthermore, if in this preferred embodiment, the reservation station 120 is full and data to be written are further transferred from the branch instruction control unit, at least one piece of data being stored
 5 can be written. Figs. 23 and 24 show this preferred embodiment.

Fig. 23 shows an example circuit configuration of a circuit for compulsorily writing in a branch history.

10 If the valid signal of an entry from a circuit shown in Fig. 24 (+RSW_x_VALID) is inputted to an AND circuit 201 and all the entries of all the reservation stations 120 are valid, the reservation stations are full. Therefore, in this case, a signal indicating
 15 this +RSW_FULL is outputted. If the update of the branch history 20 is valid, +BRHIS_UPDATE_VALID inputted from the branch instruction process unit 17 becomes ON, a signal for compulsorily writing in a reservation station +FORCE_WRITE_BRHIS is generated
 20 and used in the operation shown in Fig. 19.

Fig. 24 shows an example configuration of the valid circuit of a reservation station 120.

If the update of the branch history 20 is valid (+BRHIS_UPDATE_VALID is ON) and the entry RSW0 of the
 25 No. 1 branch histories of a reservation station 120

a maximum of two piece of data can be written in this preferred embodiment.

For example, according to a set associative system, a lot of writing can also be simultaneously performed by controlling a way by +CREATIVE_NEW, 5 +UPDATE_OLD_ENTRY, +ERACE_ENTRY or another way selecting signal, etc.

Fig. 25 shows an example configuration of a reservation station in the case where writing in the reservation station is available after the completion of an instruction execution under IID (Instruction ID) control. 10

In Fig. 25, in addition to the configuration shown in Fig. 16, the reservation station 120 (120-2) is configured to register both a CSE-Valid flag, which 15 is described later, and the IID of the instruction completion process unit 19. By doing this, a signal RSWx_CSE_VAL shown in Fig. 26 can be utilized, and whether an instruction is executed and completed can be judged. 20

A CSE-Valid flag is turned off by comparing the ID of an executed and completed instruction inputted from the instruction complete process unit 19 (COMMIT_BR_IID) with IID entries in the reservation station 120. If an instruction execution is 25

09532275-032100

temporarily stopped due to an interruption, etc., the CSE-Valid flag is compulsorily turned off by a signal +FLUSH_RS. By doing this, an entry corresponding to an instruction for which the execution could not be completed due to an interruption, etc., does not remain.

If the CSE-Valid flag is ON, the execution of an instruction is not completed yet. Therefore, a signal obtained by suppressing a signal +RSWx_VALID using this flag can be transmitted to a write selection circuit instead of +RSWx_VALID shown in Fig. 18.

Fig. 26 shows an example configuration of the CSE valid circuit of a write reservation station.

The update valid signals of the branch history 20 of the respective entries RDW0-RSW3 of the No. 1 through No. 3 branch histories of the reservation station 120 (+BRHIS_UPDATE_VALID) are ON and the reservation station 120 is invalid (-RSWx_VALID is ON) or if the reservation stations are full (+RSW_FULL is ON) and the reservation station 120 is selected (+SEL_RSWx_WRITE), concerning the No. 0 branch history of the reservation station 120, a signal is inputted to the set ports of flip-flops 221-1 - 221-4, and a signal +RSWx_CSE_VALID is outputted. The same process applies to the No. 1 through No. 3 of the reservation

001220"5222560
09532275-032100

station 120. However, in these cases, a priority circuit 223 is provided in mid-course. This priority circuit 223 is configured in such a way that priority decreases in ascending order of the number of reservation stations.

If COMMIT_BR_IID inputted from the instruction completion process management unit 19 in a cycle W and RSWx_IID recorded in the reservation station 120 are compared by comparators 222 (222-0 - 222-3) and if the signals match, the flip-flops 221-1 - 221-4 are reset. If a signal +FLUSH_RS outputted at the time of re-instruction fetch is inputted, the flip-flops 221-1 - 221-4 are also reset. Alternatively, if -RSWx_VALID, which is a signal obtained by logically inverting the output of the circuit shown in Fig. 24, is ON, the flip-flops 221-1 - 221-4 are reset.

If in a circuit shown in Fig. 26, a signal -RSWx_VALID is simultaneously inputted to OR circuits 224-0 - 224-3 and AND circuits 225-0 - 225-3, there is a possibility that a set signal and a reset signal may be simultaneously inputted. In this case, the circuit is configured in such a way that priority is given to the set signal.

Fig. 27 shows the data storage configuration of the write reservation station shown in Fig. 25.

If branch history information is inputted to a latch circuit 230 and +RSWx_VALID becomes ON, the branch history information is stored and outputted as RSWx_ branch history information.

5 Here, x corresponds to the digits 0 through 3, and the same number of the circuit shown in Fig. 27 as the entries of the reservation station 120, specifically, the number of entries of No. 1 through No. 3 branch histories of the reservation station 120
10 are provided.

Fig. 28 shows an example configuration of a CSE valid circuit in the case where a branch prediction unit is provided with a return address stack.

15 A return address stack is configured to operate if a completed branch instruction (to write history information) corresponds to a sub-routine call instruction or sub-routine return instruction.

20 When there is a temporary execution stoppage due to an interruption, etc. (a signal +RS1 is ON), it is sufficient if information indicating that the instruction corresponds to the sub-routine call or return of the branch history information which exists in the reservation station 120 is nullified instead of turning a Valid signal (the CSE-Valid flag of the
25 reservation station 120) (see Fig. 25) off. It is

sufficient if the branch history information is written in a timing available at this point. Therefore, the CSE-Valid flag is reset.

+SET_RSWx_CSE_VAL and +RST_RSWx_CSE_VAL shown in
5 Fig. 28 correspond to signals inputted to the respective set and reset terminals of the set/reset flip-flops 221-1 - 221-4 shown in Fig. 26.

Two portions including the flip-flops 241-1 and 241-2 located in the lower section are extracted to
10 indicate that the portions are the sub-routine call instruction and sub-routine return instruction of the branch history information shown in Fig. 27.

Specifically, if +SET_RSWx_CSE_VAL is inputted, the set/reset flip-flop 242 is set and +RSWx_CSE_VAL
15 is turned ON. If +RST_RSWx_CSE_VAL is inputted or +RS1 becomes ON, +RSWx_CSE_VAL is reset and turned OFF.

If +RS1 is ON and +RSWx_CSE_VAL is also ON, the output of an AND circuit 244 becomes "0" and the flip-flops 241-1 and 241-2 are reset. If +RSWx_VALID, which
20 is the output of the circuit shown in Fig. 24, is OFF and the instruction is a sub-routine call instruction, +BR_COMP_SUBROUTINE_CALL becomes ON and is inputted to the flip-flops 241-1 and 241-2. In this case, if the instruction is a sub-routine return instruction,
25 +BR_COMP_SUBROUTINE_RTN becomes ON and is inputted to

the flip-flops 241-1 and 241-2.

Specifically, if an instruction execution is not completed ($+RSW_CSE_VAL = 0$) or there is no temporary execution stoppage due to an interruption, etc., ($+RS1 = 0$) and the entry of the reservation station 120 is valid ($+RSW_VALID = 1$), an ON signal is inputted to the terminal IH of the flip-flops 241-1 and 241-2, and a signal indicating that the instruction is a sub-routine call instruction or a sub-routine return instruction is stored and outputted as $+RSW_SUBROUTINE_CALL$ or $+RSW_SUBROUTINE_RTN$.

Fig. 29 shows an example circuit for nullifying the entry of the reservation station if an instruction execution is temporarily stopped due to an interruption, etc.

$+SET_RSW_VAL$, which is a signal to be inputted to the set terminal of each of the flip-flops 211-1 - 211-4 shown in Fig. 24, is inputted to the set terminal of a set/reset flip-flop 251 and is outputted as $+RSW_VALID$. If $+RST_RSW_VAL$ to be inputted as the reset signal shown in Fig. 24 is inputted or an execution is temporarily stopped due to an interruption, etc., ($+RS1 = 1$) and an instruction execution is not completed yet ($+RSW_CSE_VAL = 1$), the set/reset flip-flop 251 is reset.

00532275-032100

Fig. 30 shows one preferred embodiment of a bypass hit circuit.

An address comparison (branch prediction) unit 263 comprised of seven comparators 265 (265-1 - 265-7) varies depending on the nature of the branch prediction method of the branch history 20 and should be appropriately configured by a person having ordinary skill in the art. Therefore, only a brief description is made of the address comparison unit 263. Writing is bypassed and data in the write reservation station 120 and branch prediction unit (RSBRx in Fig. 30) can be designated as a search target by generating a branch destination address BRHIS_TIAR.

Specifically, the address comparison unit 263 compares an inputted address IF_EAG requested to be read with the branch history 20 (BRHIS-RAMs #0 and #1), the entries #RSW0-3 of the reservation station 120 and an instruction addresses IAR which are outputted from the branch prediction unit #RSBRx. If these respective compared signals match, the address comparison unit 263 outputs corresponding branch destination address TIAR from selection circuits 267-1 - 267-7. Then, one of these signals is selected by a selection circuit 268 and is outputted as the branch

09532275-032100

destination address of the branch history (BRHIS_TIAR). If in the branch prediction unit, a branch destination address generated inside is valid and the branch prediction succeeds, the address comparison unit outputs a branch destination instruction address to the selection circuit 267-7.

By combining the configurations described above, the performance of the information processing apparatus can be improved.

Although in the preferred embodiments described above, a lowercase x is attached to the ends of symbols, like RSWx for example, in the case of a reservation station, this means that a lowercase x can take digits 0 through 3 and there are configurations and signals corresponding to the respective digits. In other cases, an x suffix means that there are the same number of configurations and signals corresponding to symbols with the suffix as the number indicated by the suffix, and represents the configurations and signals.

According to the present invention, in the execution of a branch instruction, an instruction fetch request can be processed with priority by delaying the timing of writing of an entry in a branch history, and the process delay can thereby be avoided.

Furthermore, according to the present invention,
if the branch history of a branch instruction which
has not been actually executed is reported, the branch
history is registered, but a return address stack is
5 not operated. Therefore, the correspondence between
a subsequent sub-routine call and a subsequent sub-
routine return is prevented from collapsing, and
thereby failure in the prediction of the branch
destination address of a sub-routine return
10 instruction can be reduced.

00532275 032400